Land use change and ecosystem service provision in Pampas and Campos grasslands of southern South America

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Supplementary material for this article is available online

Abstract

New livestock production models need to simultaneously meet the increasing global demand for meat and preserve biodiversity and ecosystem services. Since the 16th century beef cattle has been produced on the Pampas and Campos native grasslands in southern South America, with only small amounts of external inputs. We synthesised 242 references from peer-reviewed and grey literature published between 1945 and mid-2015 and analysed secondary data to examine the evidence on the ecosystem services provided by this grassland biodiversity hotspot and the way they are affected by land use changes and their drivers. The analysis followed the requirements of systematic review from the PRISMA statement (Moher *et al* 2009 *Acad. Clin. Ann. Intern. Med.* **151** 264–9). The Pampas and Campos provide feed for 43 million heads of cattle and 14 million sheep. The biome is habitat of 4000 native plant species, 300 species of birds, 29 species of mammals, 49 species of reptiles and 35 species of amphibians. The soils of the region stock 5% of the soil organic carbon of Latin America on 3% of its area. Driven by high prices of soybean, the soybean area increased by 210% between 2000 and 2010, at the expense of 2 million ha (5%) of native grassland, mostly in the Pampas. Intensification of livestock production was apparent in two spatially distinct forms. In subregions where cropping increased, intensification of livestock production was reflected in an increased use of grains for feed as part of feedlots. In subregions dominated by native grasslands, stocking rates increased. The review showed that land use change and grazing regimes with low forage allowances were predominantly associated with negative effects on ecosystem service provision by reducing soil organic carbon stocks and the diversity of plants, birds and mammals, and by increasing soil erosion. We found little quantitative information on changes in the ecosystem services water provision, nutrient cycling and erosion control. We discuss how changing grazing regimes to higher forage allowance can contribute to greater meat production and enhancing ecosystem services from native grasslands. This would require working with farmers on changing their management strategies and creating enabling economic conditions.

1. Introduction

While global demand for meat is predicted to grow in the next decades (OECD 2007), there is widespread concern about the negative environmental effects of current models of livestock production (de Vries and de Boer 2010, Steinfeld *et al* 2010, Gerber *et al* 2013, Alkemade *et al* 2013, Petz *et al* 2014). New models of livestock production are needed to address the increasing demand for meat while preserving biodiversity and ecosystem services. Ecologically intensive agriculture has been proposed as a means to attain greater resource use efficiency and reduced need for external inputs through increased reliance on functional biodiversity (Doré *et al* 2011, Bommarco *et al* 2012, Tittonell 2014). The traditional livestock systems in the Pampas and Campos of the *Río de la Plata grasslands* region in southern South America may be considered ecologically intensive models of meat production that evolved from the early cattle production systems introduced by the European settlers. Beef cattle is produced on species-rich native grasslands with negligible amounts of external inputs (Viglizzo *et al* 2001). Over the past decades, cropping replaced substantial areas of native grassland, leading to likely irreversible destruction of vast areas of the grassland biome (Naylor *et al* 2005). Despite the historical, cultural and economic importance of these low external input meat production systems, information about the ecosystem services they provide and the changes they are subject to is limited and fragmented (Payret *et al* 2009, Medan *et al* 2011, Balvanera *et al* 2012). This knowledge gap impedes science-based assessment of their role as an alternative model of meat production and of the consequences of land use changes for the provision of ecosystem services (Baldi and Paruelo 2008, Vega *et al* 2009).

Here we systematically review the evidence on land use in the Pampas and Campos, the ecosystem services provided by the native grasslands and how these were affected by land use change in recent years. We addressed the following questions: (1) What is the current ecological and agricultural diversity in the *Río de la Plata grasslands* region? (2) How did land cover and land use change over time? (3) What is the level of ecosystem service provision by native grasslands? Based on our findings, we discuss current thinking about options for increasing meat productivity while preserving biodiversity and associated services.

2. Materials and methods

2.1. Data collection

We conducted a systematic review of land use change and ecosystems services in the *Río de la Plata grasslands* region based on peer-reviewed and grey literature. A search of peer-reviewed articles through the Web of Science (Thomson Reuters, New York, USA) was performed on 20 June 2015 with the following keywords: Río de La Plata grasslands (22 results); Campos grasslands (178 results); Pampas grasslands (444 results). The keywords correspond to the different colloquial names of the *Río de La Plata grasslands* region, with a focus on native grasslands. Additional search criteria were English, Spanish and Portuguese as language and publication date between 1945 and 2015. The first article was published in 1988; 53% of the articles were published after 2005. Of the resulting 644 articles, the title and/or abstract of 174 matched the scope of this study by quantifying the current state of at least one ecosystem service; quantifying modifications in the provision of ecosystem services resulting from anthropogenic activities; or quantifying changes in land use over time.

Additional sources of information were identified through the on-line library system of Wageningen University and Research Centre. Furthermore, we contacted 15 experts on land use and ecosystem services in the *Río de la Plata grasslands* region from Argentina, Uruguay and Rio Grande do Sul (Brazil), who facilitated access to grey literature and databases published in Spanish or Portuguese. This yielded 68 additional publications, adding up to 242 publications in total.

Census data from Argentina (2002), Brazil (2006) and Uruguay (2000 and 2010) and regional surveys from Argentina (2010), Brazil (2005) and Uruguay (2012 and 2013) were used to characterise the structure of the agricultural sector in terms of farm sizes, main sources of income and land use (INDEC 2002, MGAP 2002, 2012a, SEBRAE, SENAR and FARSUL 2005, IBGE 2006, Antuña *et al* 2010, Calvi 2010, MGAP 2013b). Aboveground net primary production of grasslands from 2000 to 2010 was obtained from on-line data (LART 2013). Rainfall and temperature data came from meteorological stations in the region (INIA 2013, INTA 2015, Ministerio da Agricultura; Pecuária e abastecimento 2015).

2.2. Data processing and strength of evidence

The definition of the geographic limits of the region and its subregions was based on the different vegetation communities reported in the literature (León *et al* 1984, Soriano 1992, Boldrini 1997, Viglizzo and Jobbágy 2010, Brazeiro *et al* 2012). Changes in land use and livestock densities were calculated from the census data and regional surveys, and mapped at the level of subregions. Maps were built using Quantum GIS Desktop 2.2.0 (QGIS 2014).

For each of the 242 articles we listed which attributes and drivers of the ecosystem services had been studied, and the resulting trends. Attributes comprised the quantitative measures of an ecosystem service (e.g. plant species richness as an attribute of floristic diversity), and drivers included the external forces that affected the value of the attributes (e.g. land use change). Observed trends in attributes were classified as increase, decrease or no change.

To ensure the credibility and reproducibility of the systematic review, we designed and reported this study according to the PRISMA statement (Moher *et al* 2009), which provides guidelines for reporting systematic reviews and meta-analyses. The items checklist for this study is included as supplementary material 1. An overview of the sources of information can be found in supplementary material 2.

The strength of evidence of each study was represented on a three-point scale based on the methods

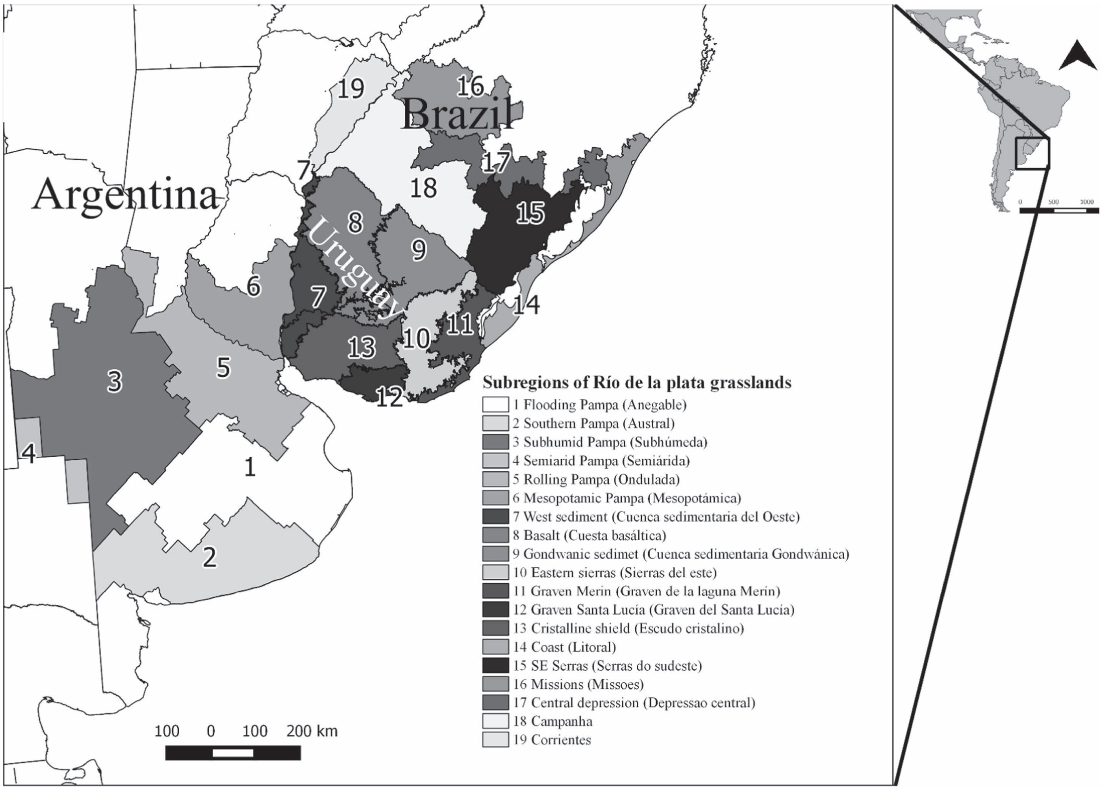

Figure 1. Subregions of Río de la Plata grasslands (León *et al* 1984, Soriano 1992, Boldrini 1997, Brazeiro *et al* 2012). Local names of the subregions are in parentheses.

used in the study. High strength evidence (value = 3) corresponded to studies from controlled field experiments, observations with sound methodologies, or meta-analyses; intermediate strength evidence (value = 2) included narrative reviews; and low strength evidence (value = 1) included publications based on opinion.

3. Diversity of beef production systems in the region

Río de la Plata grasslands is a region of 700 000 km^2 comprising parts of Argentina and Brazil and the whole of Uruguay (28°–38°S; 47°–67°W). Landscape heterogeneity in the region is reflected in subregions that are defined by vegetation communities associated with edapho-topographic characteristics (Soriano 1992, Hasenack *et al* 2010, Brazeiro *et al* 2012) (figure 1 and table 1). Climate conditions differ following southwest to northeast gradients in annual precipitation (from 700 to 1600 mm) and average annual temperature (from 14 °C to 22 °C). The climatic gradients determine the relative dominance of C3 and C4 grass species (Burkart 1975), giving rise to two major biomes: Pampas and Campos. While C3 species dominate in the Pampas of Argentina, the Campos of Brazil and Uruguay are dominated by C4 grasses, although in winter the biomass of C3 species increases substantially in the Uruguayan Campos (Berretta *et al* 2000).

The native grasslands constitute the main source of feed for 43 million heads of cattle and sustain the livelihoods of 260 000 farm households (INDEC 2002, IBGE 2006, MGAP 2013b). Farm size in terms of land and cattle heads vary among regions (table 1). Most of the farms (81%) and 66% of the land are owned by families. The remainder is owned by corporations (INDEC 2002, IBGE 2006, MGAP 2013b).

Two types of beef production systems can be distinguished: reproduction oriented or 'cow-calf' systems and meat production or 'finishing' systems (Beauchemin *et al* 2010). Farms may be specialised in one of these types, but combinations of both on a single farm are also found ('full cycle' systems) (figure 2).

Cow-calf farms specialise in animal reproduction and derive their main income from selling calves and culled cows. These farms typically also raise sheep for wool or meat production (Royo Pallarés *et al* 2005), giving rise to competition between sheep and cattle for the grassland feed resource.

Finishing systems mainly fatten male calves. Farms may specialise in 'backgrounding' (the phase from male calf to young steer) and/or 'fattening' (the phase from young steer to slaughter weight). In both systems animals may be fed on native grasslands, leys or grains (feedlots), defining different production systems with distinct shares of native grassland, crop-ley rotations

Table 1. Characteristics of the subregions of the *Río de la Plata grasslands* region ordered by biome and country.

Biome	Country	Area (million ha)[8]	Subregion[9,10]	Dominant soil types[9]	Area with native grasslands (%)[11]	Average farm size (ha)[11]	Farms with cattle (%)[11]	Ownership (%)[11,12]	Main production system[13]
Pampas (C3-dominated)	Argentina	9.3	Flooding (1)	Mollic Solonetz	68	605	93	70	Cattle (cow-calf)
		8.3	Southern (2)	Haplic/Luvic Phaeozems	29	697	81	66	Crops-cattle (finishing)
		12.9	Subhumid (3)	Phaeozems	17	526	72	66	Crops
		1.5	Semiarid (4)	Calcaric Phaeozems	7	824	89	70	Crops
		7.4	Rolling (5)	Phaeozems	33	222	48	59	Crops
		3.2	Mesopotamic (6)	Phaeozems/Eutric Vertisols	50	388	84	67	Crops-cattle (finishing)
Campos[7] (C4-dominated)	Uruguay	2.8	West sediment (7)	Eutric Vertisols/Phaeozems	54	357	78	59	Cattle (finishing), crops
		3.2	Basalt (8)	Lithic Leptosols/Phaeozems	89	728	87	67	Cattle (cow-calf), sheep
		1.2	Gondwanic sediment (9)	Haplic Luvisols/Phaeozems	79	362	65	66	Cattle (cow-calf)
		2	Eastern sierras (10)	Phaeozems	79	294	92	67	Cattle (cow-calf), sheep
		2.2	Graven Merin (11)	Mollic Planosols	71	393	74	63	Cattle (cow-calf), rice
		1	Graven Santa Lucía (12)	Phaeozems	41	57	74	64	Cattle (full cycle), dairy, horticulture
		2.6	Crystalline shield (13)	Phaeozems	69	395	93	59	Cattle (full cycle), dairy
	Brazil	0.7	Litoral (14)	Dystri-Ferralic Arenosols	64	126	68	81	Horticulture, rice, cattle (cow-calf)
		3.9	SE Sierras (15)	Alisols/Regosols/Lixisols	54	56	79	82	Cattle (cow-calf), sheep
		2.9	Missons (16)	Ferrasols/Leptosols/Arenosols	31	53	74	86	Crops
		3.3	Central depression (17)	Planosols/Alisols/Acrisols	44	53	71	84	Rice, cattle (finishing)
		2.4	Campanha (18)	Leptosols/Plinthosols/Phaeozems/Vertisols	70	204	82	83	Cattle (cow-calf)
	Argentina	2.7	Corrientes (19)	Ferrasols/Luvisols/Solonetz	85	928	82	80	Cattle (cow-calf)

[7] This biome can be divided into the northern Campos, in southern Brazil and northeast Argentina, and the southern Campos in Uruguay.

[8] Calculated from (INDEC 2002, MGAP 2002, Berretta 2003, IBGE 2006, Viglizzo and Jobbágy 2010).

[9] Defined after (Soriano 1992, Boldrini 1997, Berretta 2003, Viglizzo and Jobbágy 2010, Brazeiro *et al* 2012).

[10] Numbers refer to the regions in figure 1.

[11] Calculated from (INDEC 2002, MGAP 2002, IBGE 2006, Viglizzo and Jobbágy 2010).

[12] Percentage of the area owned by farmers. The remainder is owned by corporations or rented.

[13] Defined after INDEC (2002), MGAP (2002), Antuña *et al* (2010), Viglizzo and Jobbágy (2010), SAGyP and INTA (2013), and Boldrini (2007).

(mixed crop-livestock systems) or continuous crop rotations.

Steer-to-cow ratios of less than 0.4 indicate specialisation in the cow-calf system, ratios of 0.4–1.2 indicate full cycle farm systems, and ratios greater than 1.2 specialisation in finishing beef cattle (Rossanigo *et al* 2012) (figure 2).

4. Land use dynamics

Today, more than 80% of the *Río de la Plata grasslands* region is covered by native grasslands, sown pastures as part of crop-pasture rotations (leys) (Allen *et al* 2011) and annual crops (INDEC 2002, IBGE 2006, MGAP 2013b). Tree plantations and natural forests cover the remaining 20% of the area. Before the arrival of European settlers, the entire region consisted of native grasslands (Behling *et al* 2005, 2009, Tonello and Prieto 2008). After the introduction of domesticated livestock from Europe in the 16th century the ecosystem was shaped by grazing and fire (Overbeck *et al* 2006, Bernardi *et al* 2016). Tillage, sowing of exotic species and fertilisation was limited to small areas (Díaz *et al* 2006). The absence of large predators and the relatively high net primary productivity of the grasslands (Soriano 1992) allowed rapid expansion of the introduced livestock, leading to changes in the original plant and animal communities. The presence of dominant native plant species declined and tree species were introduced (e.g. *Ligustrum lucidum, Phoenix canariensis, Populus spp* and *Eucalyptus spp*) together with exotic bird species (e.g. *Furnarius rufus* and *Myiopsitta monachus*) (Bilenca *et al* 2009).

Arable farming was introduced in the region in the late 19th century. Between 1860 and 1910 the wheat area increased from 325 000 ha to 15 500 000 ha, along with a 16 fold increase in the population of European immigrants in the Argentinean Pampas and an expansion of railroads from 6 to 17 350 miles (Scobie 1964). These changes further reduced the number of native grassland species and increased the number of exotic species, many of which came in as weeds with the seeds of cereals (Ghersa and Leon 1999).

High animal stocking rates on native grasslands and subsequent overgrazing resulted in soil erosion with loss of soil carbon, and in loss of grassland species diversity (Overbeck *et al* 2007). This resulted in low grassland and meat productivity (60 kg live weight (LW) ha^{-1} yr^{-1}), four times less than what is achievable by improved grazing management (Carvalho *et al* 2009a, Nabinger *et al* 2011, Da Trindade *et al* 2012).

Since 1970, the area of native grasslands declined steadily due to the expansion of grain crops, especially wheat and soybean, and to a lesser extent tree plantations (Baldi and Paruelo 2008) (figure 3). Rates of land use change after 1990 were higher than during the previous 20 year-period, when more than 15% of the native grassland area was lost (figure 3) and fragmented (Paruelo *et al* 2006).

Cultivation of genetically modified, herbicide-resistant soybean was the most important reason for land use change between 2000 and 2010. The soybean area increased by 210% and the total arable cropping area by 28%, while the native grassland area decreased by 5% during this decade (figure 4(a)). This expansion was driven by favourable soybean prices, which increased 2.1 fold between 2000 and 2010 (figure 4(a)), by the relatively low production costs and by the introduction of new technologies such as no-tillage (Trigo and Cap 2004, Grau *et al* 2005, Altieri and Pengue 2006, Baldi and Paruelo 2008, Bindraban *et al* 2009, Caride *et al* 2012, Redo *et al* 2012). Despite the decrease in grassland area, cattle numbers remained stable in response to favourable beef prices (figure 4(b)).

Expansion of cropping is associated with higher land prices and increased use of agricultural inputs. For instance, in Uruguay the price of land increased sixfold and the imports of fertilisers and pesticides tripled between 2000 and 2010 (figure 5(a)). Over this period, animal production was intensified, as reflected by a 20% decrease in the slaughter age of steers due to shorter production cycles, and by 10% higher stocking rates (figure 5(b)).

Crop area increased in 16 subregions, which together represent 95% of the area of the *Río de la plata grassland* region (figure 6(a)). In half of these subregions (denoted as 'Increase–increase'), cattle numbers increased alongside the crop area. In the other half (denoted as 'Increase–decrease'), cattle numbers decreased (figure 6(b)).

Cattle numbers and thus stocking rates increased in subregions where native grasslands constituted the dominant land use, covering more than 60% of the area (figure 7). In subregions with less than 30% native grassland area, cattle numbers consistently fell, while subregions with 30%–60% native grasslands represented a transition group (figure 7). Although feedlots were present in most subregions, the largest proportions of animals finished in feedlots were associated with subregions with less than 60% of the area under native grasslands (figure 7). There was a positive linear relationship between increase in cattle heads and proportion of native grasslands area ($R^2 = 0.75$, $p < 0.001$), indicating that cattle stocking rates increased in native grasslands areas, and decreased in areas dominated by crop production (intensification and relocation). This indicates that cropland expansion and livestock intensification by increased stocking rates or by an increased share of grains in the diet were spatially linked developments in the region.

Full cycle and finishing farm systems were more important in subregions where crops increased and cattle decreased (Increase–decrease subregions), and where most of the animals were grown in feedlots. Cow-calf farm systems dominated the Increase–

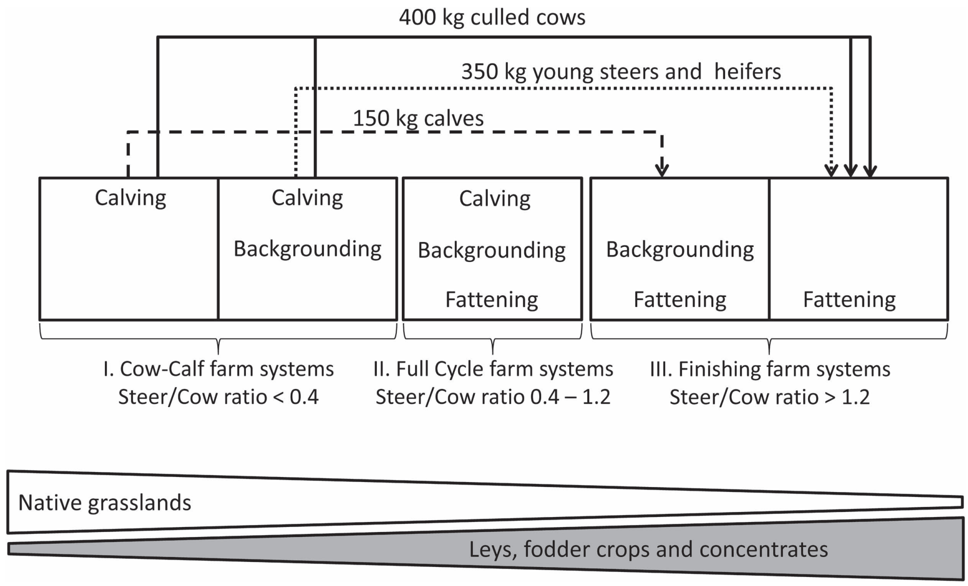

Figure 2. Main livestock production systems in the *Río de la Plata grasslands* region. Numbers indicate the weight of an animal when leaving a production system. Arrows indicate the flow of animals from one production system to the next. From left to right the importance of native grassland as source of animal feed declines and feed from exotic species increases. Based on Arzubi *et al* (2013), Modernel *et al* (2013), Becoña *et al* (2014).

increase subregions, where stocking rates increased (figure 8). This increase in stocking rates in the subregions where native grasslands dominate may exacerbate overgrazing, a longstanding problem in the region (Overbeck *et al* 2007, Carvalho *et al* 2009a, 2009b).

5. Ecosystem services and impact of human intervention

The ecosystem services reported for the *Río de la Plata grasslands* region included provisioning, supporting and regulating services. In the next sections, we summarise evidence on primary and secondary production, floristic diversity, animal diversity, climate regulation, water provision, nutrient cycling and erosion control. The drivers of change include the impacts of external inputs (fertilisers, pesticides and concentrate feedstuff for animals), fire, flooding, land use change, grazing and grazing management. The term ‘grazing’ denotes the effect of grazing as compared to grazing exclusion. ‘Grazing management’ is concerned with the decisions on the frequency and intensity with which livestock graze the paddocks. Grazing management gives rise to different levels of forage allowance (kg DM kg^{-1} animal LW), as defined by Sollenberger *et al* (2005). We considered animal stocking rate as inversely proportional to forage allowance, i.e. high stocking rate corresponds to low forage allowance. Since ‘overgrazing’ results in low forage allowance, we used ‘low forage allowance’ in the description of drivers affecting ecosystem services provision.

5.1. Provisioning ecosystem services: aboveground net primary and meat production

In 2012 the aboveground net primary production of the *Río de la Plata grasslands* region (either grass or grains) provided nutrition for 8% of all cattle and 17% of all sheep in the Americas using 1.6% of the area (FAO 2013). At the same time the exports from the region accounted for 3.4% of globally exported boneless meat, which was produced on 0.3% of the global land area (FAO 2013).

Analysis of aboveground net primary productivity in five subregions (*Southern* and *Flooding Pampas*, *Eastern Sierras, Basalt* and *Corrientes*) between 2000 and 2010 showed that between 60% and 70% of the annual production occurred in spring and summer (figure 9). Aboveground net primary production in summer was strongly determined by rainfall, which showed a high degree of inter-annual variability (AIACC 2006, Bidegain *et al* 2012).

A common practice to increase aboveground net primary productivity in the region has been to replace native grasslands by grass-legume leys (Nabinger *et al* 2000). Compared to leys, native grasslands were found to produce less biomass in average years in the more temperate southern latitudes of the region (*Southern Pampas* and *Flooding Pampas*). Aboveground net primary productivity of leys and native grasslands were similar in the Southern and Northern Campos (*Eastern Sierras* and *Basalt*) (figure 9). In the warmer and wetter northern parts of the Northern Campos (*Corrientes*), native grasslands achieved higher aboveground net primary productivity than leys (figure 9).

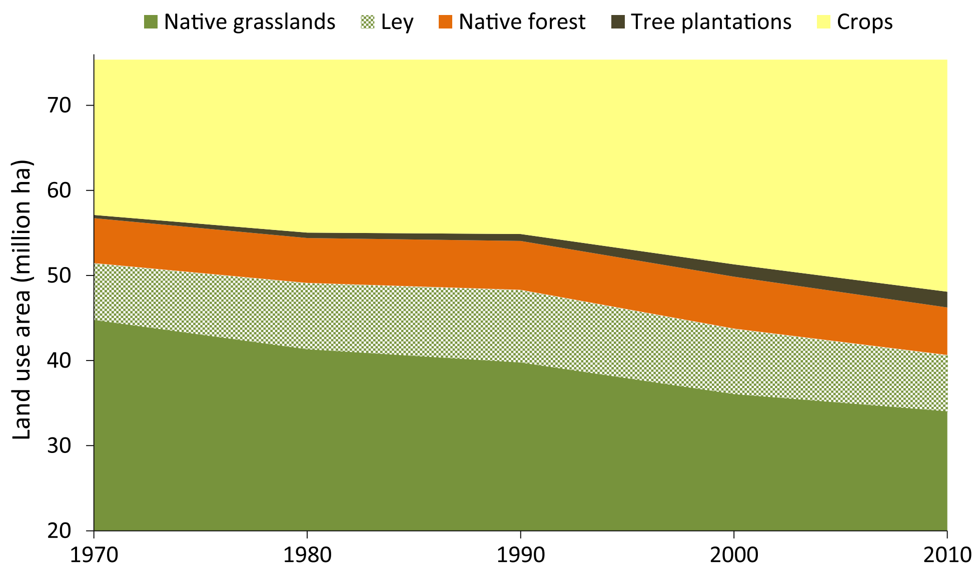

Figure 3. Evolution of land use in *Río de la Plata grasslands* region between 1970 and 2010. Data include the whole state of Rio Grande do Sul (Brazil). Built from Viglizzo and Jobbágy (2010); MGAP INDEC (2002), (MGAP 2013a), and IBGE (2014).

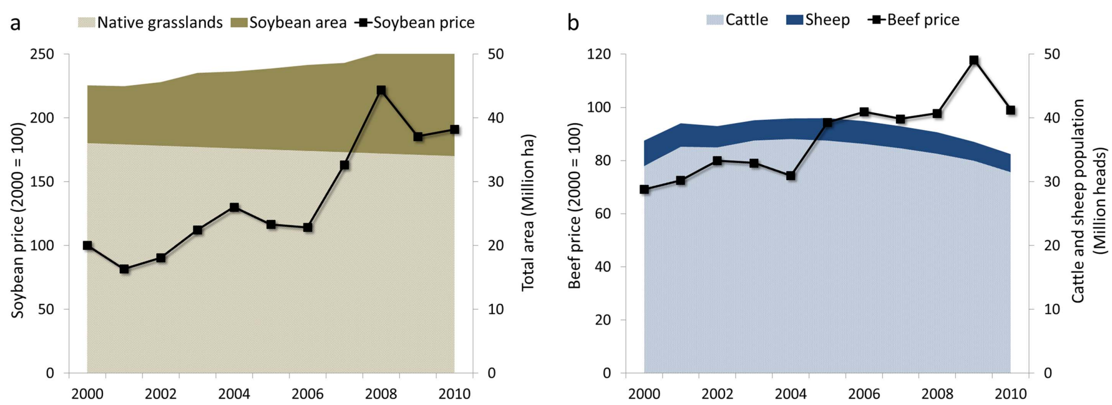

Figure 4. Land use and livestock dynamics in *Río de la Plata grassland* region between 2000 and 2010. (a) Evolution of soybean prices (relative to 2000) (FAO 2013) and of cumulative soybean and native grassland area (million ha). Built from MGAP (2002), INDEC (2002, 2009), IBGE (2006), Viglizzo and Jobbágy (2010), MGAP (MGAP 2013a) MGAP (2013b). (b) Evolution of beef prices (relative to 2000) (FAO 2013) and of the cumulative cattle and sheep population (million animal units). Built from MGAP (2002), Indec (2009), IBGE (2006), Viglizzo and Jobbágy (2010), MGAP (2013a).

5.2. Floristic diversity

The *Río de la Plata grasslands* were reported to comprise between 2000 and 4000 native plant species including some shrubs and trees (Bilenca and Miñarro 2004, Overbeck *et al* 2007). *Asteraceae, Poaceae, Leguminosae* and *Cyperaceae* were the most abundant families (Overbeck *et al* 2007). Since the majority of the species is endemic, the Río de la Plata grasslands are defined as a biome (Ferreira and Boldrini 2011). Of the 3000 plant species identified in Rio Grande do Sul, Boldrini *et al* (2009) classified 58 as 'endangered', 46 as 'vulnerable', 39 as 'critically endangered' and 6 as 'apparently extinct'. An overview of the main genus, the number of species found in each subregion and the main threats for their conservation is given in table 2.

Bilenca and Miñarro (2004) identified 68 areas of high value for grassland biodiversity conservation across the region. Together the areas comprised approximately 35 000 km^2 or 5% of the region. The selection of the areas was based on 276 publications that described the size of the areas, their species richness and the presence of endemic taxa, genus or threatened species.

Low forage allowance, or high stocking rates, was frequently reported as one of the main drivers of reduced grassland species diversity in the region (Chaneton and Facelli 1991, Altesor *et al* 1998, Ghersa and Leon 1999, Altesor *et al* 2005, Overbeck *et al* 2007, Loydi 2012). Other threats to floristic diversity were the invasion of exotic species, expansion of crop and ley areas and urbanisation (table 2).

5.3. Animal diversity

Out of 54 articles dealing with animal species diversity in the *Río de la Plata grasslands* region 36 addressed

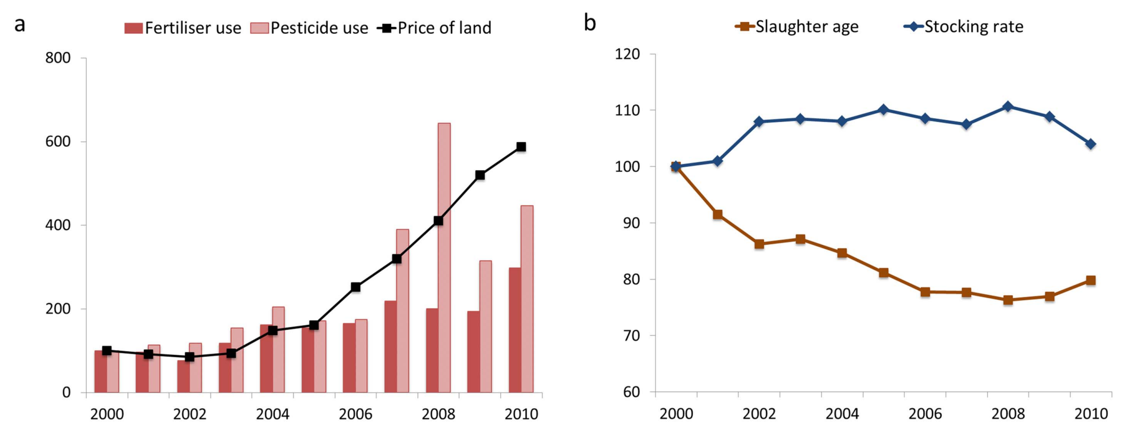

Figure 5. Dynamics of production factors and livestock intensification in Uruguay between 2000 and 2012. (a) Evolution of fertiliser and pesticide imports and of land price. (b) Evolution of average slaughter age of steers and stocking rate. Relative to year 2000 (slaughter age = 3.6 years; stocking rate = 0.68 animal units ha^{-1}. Built from (INAC 2012, MGAP 2005, 2012b, 2013a).

birds, 16 mammals and 12 insects. Medan *et al* (2011) reviewed the status of animal species, reporting 300 bird species, 36 rodent species, 29 other mammals, 49 reptiles and 35 amphibians. Bilenca and Miñarro (2004) reported between 300 and 460 avian species and 70 to 90 mammal species in Río de la Plata grasslands. Three bird species (Strange-Tailed Tyrant (*Alectrurus risora*), Eskimo Curlew (*Numenius borealis*) and Austral Rail (*Rallus antarcticus*)) and three carnivore species (Puma (*Puma concolor*), Jaguar (*Panthera onca*) and Maned wolf (*Chrysocyon brachyurus*)) were considered regionally extinct due to hunting and agricultural expansion (Medan *et al* 2011).

Azpiroz *et al* (2012) reviewed the available knowledge on grassland birds in southeastern South America, a region that includes the *Río de la Plata grasslands.* These authors reported 82 species that use grasslands for nesting and foraging, of which 22 were threatened with extinction. The area covered by grasslands in a given subregion was found to play an important role in the conservation of bird species. Codesido *et al* (2008) found higher bird species richness in *Flooding* than in the *Semiarid* and *Rolling Pampas*, where the area covered by native grasslands was less extended. Within the *Rolling Pampas*, bird species richness and abundance increased with the percentage of grassland area due to more space for breeding, foraging and dispersal (Cerezo *et al* 2011). Codesido *et al* (2013) found that land use heterogeneity at landscape level (expressed as the proportion of different land covers) promoted diversity and abundance of avian species. This is in contrast with Dotta *et al* (2015) who reported less diversity and richness of bird species in landscapes with higher proportions of grain and forest crops.

Bird species in *Río de la Plata grasslands* reacted differently to land use change. While some species (generalists) adapted, other species were more habitat-specific (grassland specialists) and their population size decreased (Isacch *et al* 2005, Codesido *et al* 2011, Gavier-Pizarro *et al* 2012, Codesido *et al* 2013, Abba *et al* 2015), resulting in eight bird species that were close to extinction (Blanco *et al* 2004, Fernández *et al* 2004, Gabelli *et al* 2004, Codesido *et al* 2012).

Vegetation structure affected bird species richness (Isacch *et al* 2014). Moderate grazing generated paddocks with heterogeneous vegetation structure (tussocks and a lower grass stratum). This heterogeneity was found to provide shelter and conserve certain species (Isacch *et al* 2003, Develey *et al* 2008, Isacch and Cardoni 2011, Cardoni *et al* 2012). The tussocks included tall grasses such as *Andropogon lateralis* and *Cortadeira selloana*, which enhanced bird species diversity to the extent that it is mentioned as a strategy for protecting endangered species (Zalba and Cozzani 2004, Zalba *et al* 2008, Di Giacomo *et al* 2010, Pretelli *et al* 2013). On the other hand, some migratory shorebird species depend on habitats with short grasses (Isacch and Martínez 2003). These authors emphasised the importance of sheep grazing in order to maintain low grass height.

The native grasslands of *Río de la Plata grasslands* region support several mammal species, such as the Molina's hog-nosed skunk (*Conepatus chinga*) (Castillo *et al* 2011, 2012), the Coypu (*Myocastor coypus*) (Guichon and Cassini 1999), Geoffroy's cats (*Oncifelis geoffroyi*) (Manfredi *et al* 2006, 2012) and short-tailed opossum (*Monodelphis dimidiata*) (Baladrón *et al* 2012). Landscape perturbation and land use change had different effects on the diversity, abundance, and distribution of rodent species depending on the initial fragmentation status of the landscape. The crop expansion in the beginning of the 20th century increased habitat heterogeneity in time and space, thus favouring rodent species diversity. In contrast, by the end of the 20th century a second crop expansion homogenised the landscape, favouring generalist species and decreasing the abundance of habitat-specialist species (Medan *et al* 2011).

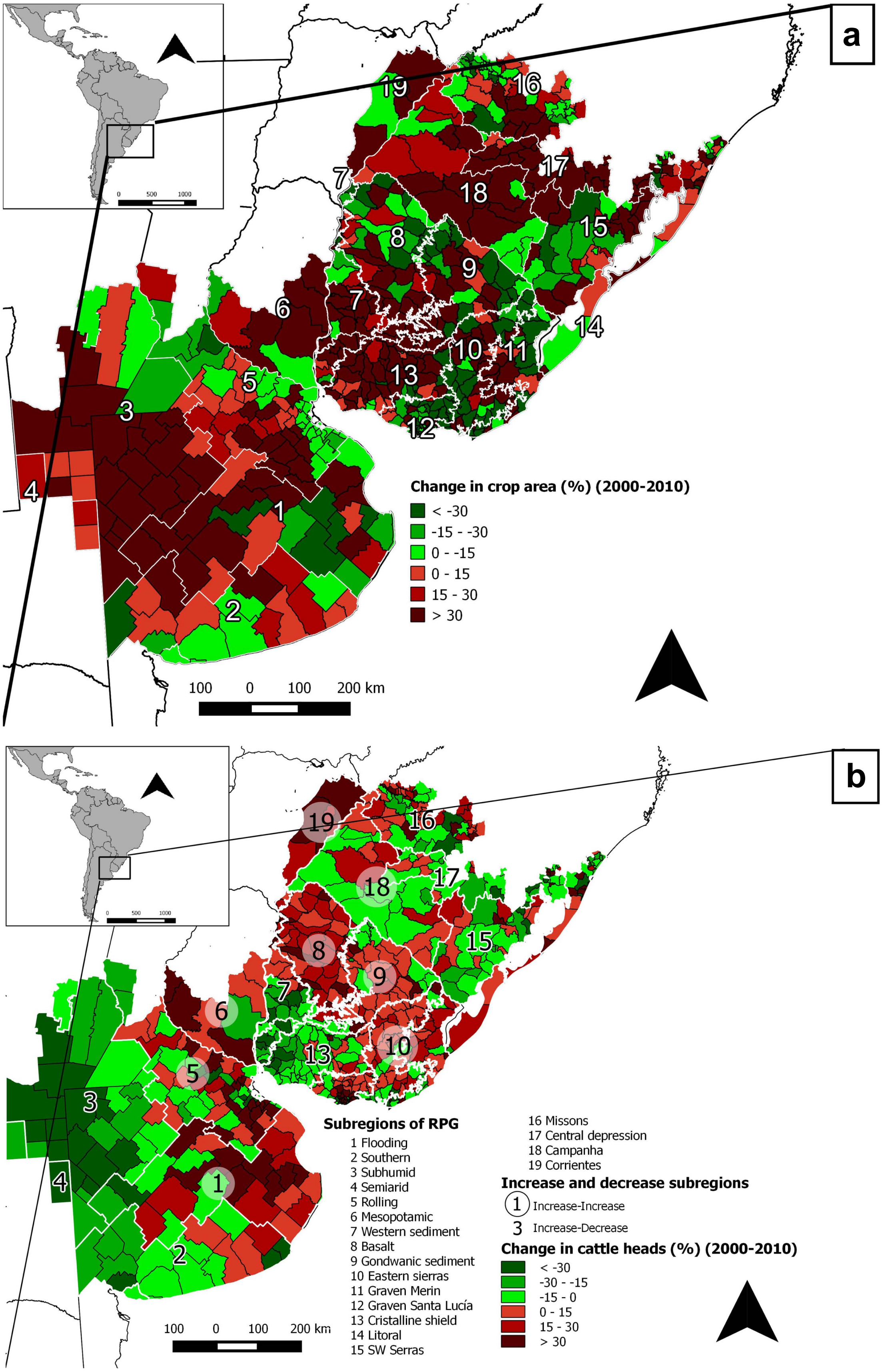

Figure 6. Change in crop area (%) and cattle population (%) in the Río de la Plata grasslands region from 2000 to 2010. (a) Relative change in crop area. (b) Relative change in number of cattle heads. Numbers indicate subregions as described in the legend. Subregions with increased crop area and cattle heads (increase–increase) and increased crop area and decreased cattle heads (increase–decrease) are highlighted in (b): Increase-Increase subregions in black numbers inside white circles (subregions 1, 5, 6, 8–10, 18 and 19) and increase–decrease subregions in black numbers with white buffer (subregions 2–4, 7, 13 and 15–17). Built from MGAP IBGE (2006), (MGAP 2012a), MGAP (2013a), MGAP (2013b).

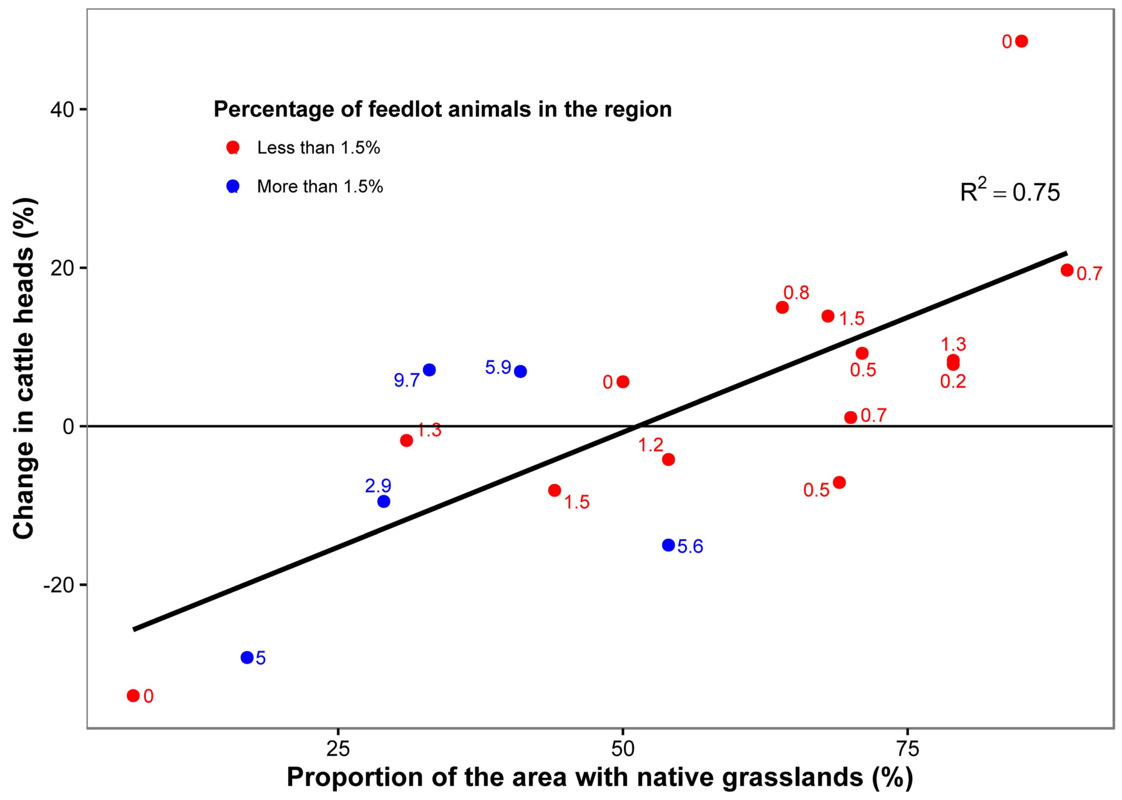

Figure 7. Relative change in cattle heads from 2000 to 2010 as a function of relative area under native grassland in the 19 subregions of *Río de la Plata grasslands* region. The relative area under native grassland was estimated from census data of 2000, 2002 and 2006 for Southern Campos, Pampas and Northern Campos, respectively. Labels indicate the percentage of heads of cattle of the subregion finished in feedlots (<1.5% for red circles and ⩾1.5 for blue circles). Built from (INDEC 2002, MGAP 2002, IBGE 2006, MGAP 2012b, 2013a, MAGyP 2014).

5.4. Climate regulation

5.4.1. Soil organic carbon stock

Covering less than 3% of the area of Latin America, the *Río de la Plata grasslands* are reported to store an estimated 5% of the total soil carbon stock of the subcontinent, with the second highest average soil organic carbon content in the first 30 cm of the soil (66 Mg ha^{-1}) after the South Chilean region (108 Mg ha^{-1}) (Bernoux and Volkoff 2006). Soil organic carbon stocks were estimated at 5400 Tg (0–30 cm) in the Argentinean Pampas (Galantini and Rosell 2006), 1530–1600 Tg (0–30 cm) in Rio Grande do Sul (Tornquist *et al* 2009) and 2300 Tg (0–100 cm, or less if the soil profile was shallower) in Uruguay (Durán 1998).

For Rio Grande do Sul, Pillar *et al* (2012) and Bernoux *et al* (2002) reported averages of soil organic carbon content of 68 and 79 Mg ha^{-1} (0–30 cm), while Tornquist *et al* (2009) reported values between 36 and 162 Mg ha^{-1}. Paruelo *et al* (2010) found lowest values of total soil organic carbon in *Basalt* and *Southern Pampas* (40 and 55 Mg ha^{-1}, respectively) and highest values in *West Sediment* (135 Mg ha^{-1}), associated with greater soil depth in the latter subregion.

Land use change from native grasslands to crops was found to result in a decline of soil organic carbon (Sala and Paruelo 1997, Díaz-Zorita *et al* 2002). Losses differed among subregions and periods of cultivation: 30% decline after 30 years in *Rolling Pampas* (Alvarez 2001), 16% and 32% after two and 14 years in the *Semiarid Pampas* (Noellemeyer *et al* 2008) and 15% after 10 years in the Northern Campos (Assad *et al* 2013).

5.4.2. Climate change mitigation

Research on greenhouse gas emissions in *Río de la Plata grasslands* region focused on identifying emission factors for enteric methane and soil nitrous oxide and estimating the carbon footprint associated with different production systems. Machado (2015) studied the effect of forage allowance of native grassland on enteric methane emission. At moderate forage allowances of 8 to 12 kg DM kg^{-1} LW, 0.8 kg CH_4 kg^{-1} LW gain was emitted, which increased by 170% at low forage allowance (4 kg DM kg^{-1} animal LW). Muscat (2015) measured enteric methane emissions of steers grazing on native, nitrogen-fertilised, and oversown (with legumes and rye-grass) grasslands. The rate of emissions on native grasslands was 0.58 kg CH_4 kg^{-1} LW gain. Fertilisation (100 kg of nitrogen ha^{-1} yr^{-1}) increased seasonal mean forage mass from 2146 to 2541 and oversowing to 2393 kg ha^{-1}. Gross protein content increased from 7.2% to 9.0% and 10.5% for native, fertilised and oversown grasslands respectively.

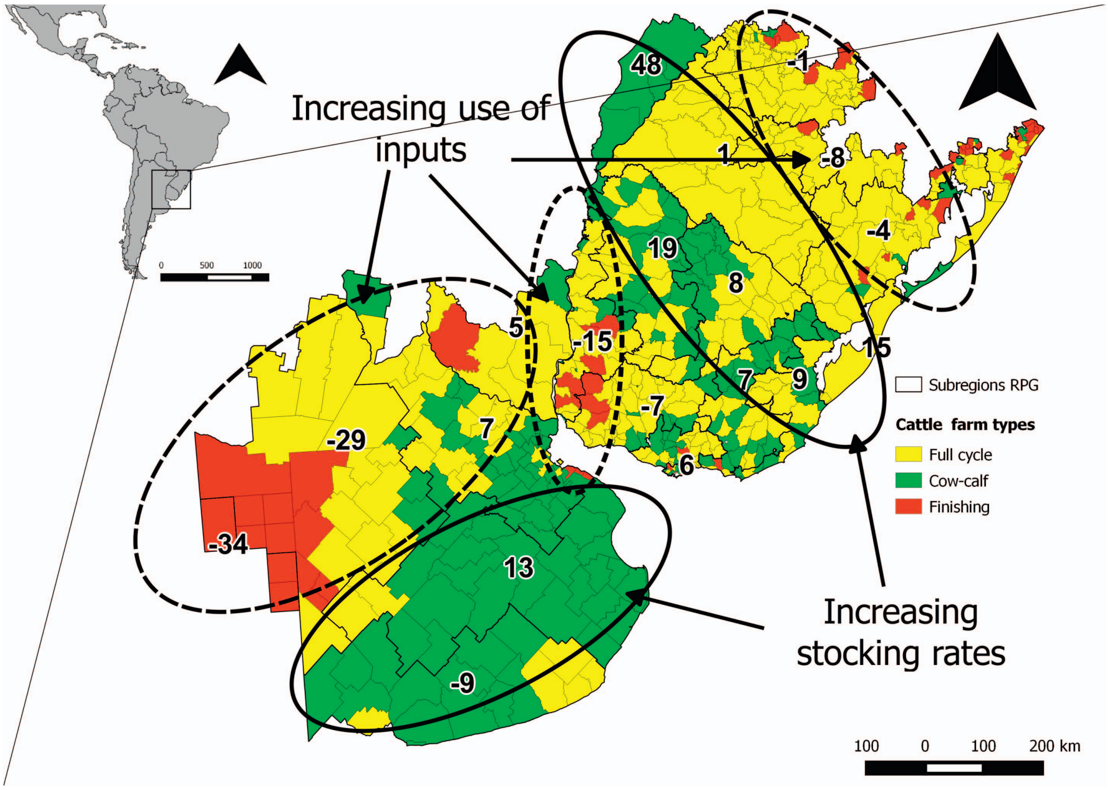

Figure 8. Cattle farm types per administrative area (the smallest spatial units) in 2000 and relative change of cattle populations per subregion (consisting of several administrative areas) of the *Río de la Plata grasslands* region between 2000 and 2010. Ellipses with solid lines show subregions where cow-calf systems dominated and cattle heads increased (associated with increasing stocking rates) and ellipses with dotted lines delimit subregions where complete cycle and finishing systems dominated and cattle heads decreased (associated with increasing use of feed inputs). Numbers indicate the change in cattle heads from 2000 to 2010 for each subregion. Built from (INDEC 2002, MGAP 2002, IBGE 2006, MGAP 2012b, 2013a, MAGyP 2014).

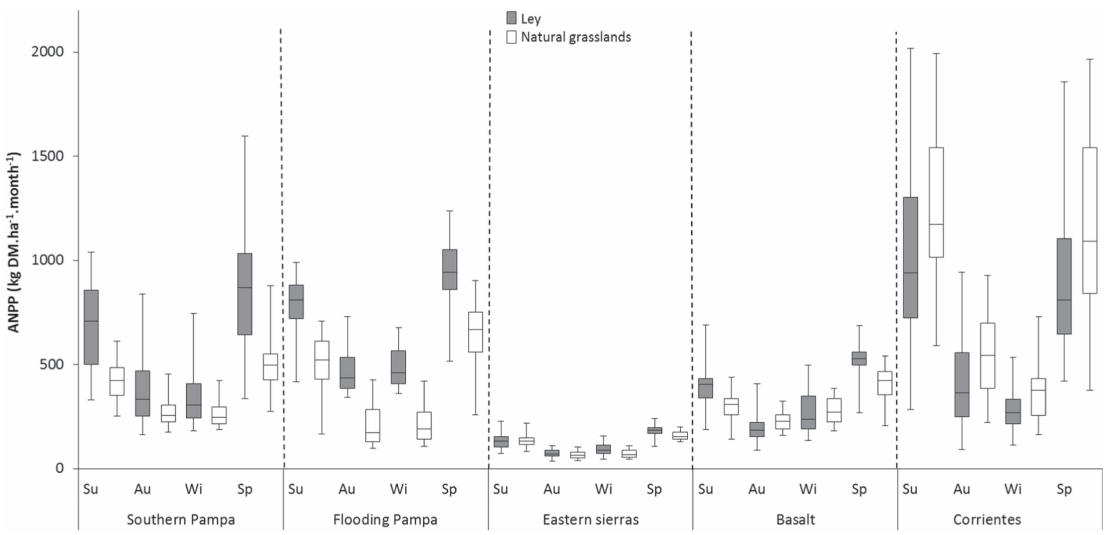

Figure 9. Box plots of seasonal aboveground net primary productivity of leys (grey) and native grasslands (white) in five subregions of the Río de la Plata grasslands region (LART 2013). Based on an 11 year dataset of aboveground net primary production (2000–2010). Boxes represent 25%, 50% and 75% quantiles; whiskers represent the minimum and maximum values. Su: summer, Au: Autumn, Wi: Winter, Sp: Spring.

As a result, grazing steers emitted 41% and 33% less methane per unit meat produced on fertilised and oversown compared to native grassland.

Perdomo *et al* (2012) reported soil nitrous oxide emission rates of 0.07 kg N_2O-N-ha^{-1} yr^{-1} from a native grassland, six times lower than from a continuously cropped no-till field and 54 times lower from a continuously cropped field under tillage.

The carbon footprint of beef cattle farms on native grassland ranged from 17.5 kg CO_2 eq kg^{-1} LW gain

Table 2. Dominant genus of vascular plants and number of species in the native grasslands of the different subregions of the Río de la Plata grasslands.

Subregion	Dominant genus of vascular plants in the native grasslands	Number of species[14]	References	Main threats for conservation[14]
Rolling Pampas	*Stipa, Paspalum, Piptochaetium, Aristida*	1600 (374 *Poaceae*)	(Vervoorst 1967, Sala *et al* 1984, Frangi and Barrera 1996, Lewis 1996, Rapoport 1996, Krapovickas and Di Giacomo 1998, Parera and Kesselman 2000)	Introduced exotic plant species
Flooding Pampas	*Bothriochloa, Paspalum, Briza, Sporobolus, Stipa, Panicum, Phalaris, Vicia, Eryngium, Glyceria, Solanum, Scirpus, Zizaniopsis, Typha, Spartina, Distichlis, Chloris, Salicornia, Limonium*			Exotic animal and plant species, expansion of crops and ley
Southern Pampas	*Stipa, Piptochaetium, Festuca, Bromus, Poa, Senecio, Plantago*			Overgrazing, crop expansion, exotic animal species
Semiarid Pampas	*Sorghastrum, Elionurus, Poa, Stipa*			Expansion of crops and ley, overgrazing
Mesopotamic Pampas	*Axonopus, Paspalum, Digitaria, Schizachyrium, Bothriochloa*			Crop expansion, urbanisation
Northern Campos	*Stipa, Paspalum, Setaria, Poa, Bromus, Piptochaetium, Melica, Trifolium, Carex, Juncus, Cyperus, Cortaderia*	2500 (400 *Poaceae*)	(Valls 1986, Durán 1991, Soriano 1992, Arballo *et al* 1999, Pacheco and Bauer 2000, Bencke 2001)	Expansion of crops and ley
Southern Campos	*Stipa, Piptochaetium, Aristida, Paspalum, Axonopus, Andropogon, Luziola, Leersia*	3000 (400 *Poaceae*)	(Boldrini 1997, Nabinger *et al* 2000)	Expansion of crops and ley, overgrazing

[14] Based on (Bilenca and Miñarro 2004).

(Picasso *et al* 2014) to 46.5 kg CO_2 eq kg^{-1} LW gain (Ruviaro *et al* 2014). Mitigation strategies in Northern Campos have been proposed through intensification of production, mainly by increasing forage production and feed quality (Ruviaro *et al* 2014, Dick *et al* 2015). These authors propose intensification pathways based on external inputs, resulting in improvement of livestock reproduction (weaning rate) and growth (average daily gain). Ruviaro *et al* (2014) estimated carbon footprint reductions of 42% by fertilising native grasslands, feeding animals with grains and using leys. Dick *et al* (2015) estimated reductions of 99.5% from a baseline scenario of 22.5 kg CO_2 eq kg^{-1} LW gain if carbon sequestration by pastures was accounted for. Further scenarios took into account the stabilisation of soil organic carbon after 20 years of gradual increase. These scenarios achieved a reduction of 68% compared to the baseline. Although these strategies decreased carbon footprint, trade-offs existed with soil erosion, pesticide use, nutrient losses, fossil fuel energy consumption and water use efficiency (Modernel *et al* 2013, Ran *et al* 2013, Picasso *et al* 2014).

5.5. Water provision, nutrient cycling and erosion control

Ran *et al* (2013) found mixed crop-livestock systems in Uruguay to be more efficient in water use than beef production systems based on feedlot or native grasslands. Water use efficiencies were 15.7, 18.9 and 19.3 m^3 water kg^{-1} LW, respectively.

Land use change from native grasslands to crops changed regional hydrology, reducing the lake areas in the *Flooding pampas* (Booman *et al* 2012). Afforestation in the *Flooding pampas* resulted in increased water uptake, reducing groundwater levels by about 0.5 m (Engel *et al* 2005).

Twelve studies investigated nitrogen and phosphorus dynamics in the *Río de la Plata grasslands* region. Garibaldi *et al* (2007) found that grazing increased nitrogen and phosphorus mineralisation, and soil nitrogen and phosphorus availability. Grazing did not change soil total nitrogen and phosphorus in an experiment by Chaneton and Lavado (1996). On the other hand, Lavado *et al* (1996) found that grazing decreased soil mineral nitrogen content and extractable phosphorus.

The impact of livestock systems intensification was studied with different methodologies. Goyenola *et al* (2015) found higher total, particulate, dissolved and reactive soluble phosphorus in a water stream of a catchment under forage crops, dairy cattle feeding all year around when compared to a native grassland with low stocking rate (lower than 1 head per ha). Two studies evaluated the impact of livestock facilities as source of point pollution for nutrients. Herrero and Gil (2008) sampled 409 water sources (water boreholes) of dairy farms in the Argentinean Pampas. Results showed that 50% of the samples were over the maximum concentration of quality standards for phosphorus. Chagas *et al* (2007) compared sediment and phosphorus concentration of the runoff of three treatments: native grasslands, native grasslands with signs of soil erosion and feedlot. Sediment concentration was 38 times higher in feedlot and 3.5 times higher in eroded grassland compared to native grassland. Reactive soluble phosphorus concentration was 0.8, 0.4 and 13.4 mg l^{-1} for native grasslands, eroded native grasslands and feedlot.

Soil erosion rates for native grasslands were lower than for croplands in all studies reviewed. For example, in well-managed native grasslands in Uruguay an average erosion rate of 2.1 Mg ha^{-1} yr^{-1} was reported (García Préchac *et al* 2004). On overgrazed grasslands with high levels of bare soil erosion rates of 6.2 Mg ha^{-1} yr^{-1} were observed (García Préchac 1992). Highest erosion rates were observed under continuous cropping with tillage, ranging from 19 Mg ha^{-1} yr^{-1} (García Préchac *et al* 2004, Wingeyer *et al* 2015) to 67 Mg ha^{-1} yr^{-1} (Jorge *et al* 2012), 3 to 9 times higher than for overgrazed grasslands. In comparison, average erosion rates of 2.3 Mg ha^{-1} yr^{-1} were reported for crop-grassland rotations (Clérici and García Préchac 2001).

5.6. Effect of drivers on ecosystem services

The most studied drivers affecting ecosystem services were land use change, grazing and grazing management, together comprising 55% of publications (table 3). A large percentage (63%) of publications dealt with the effect of the drivers on floristic diversity and animal diversity. Despite the large share of publications on grazing and grazing management (26%), the effect of these drivers on climate regulation, water provision, nutrient cycling and erosion control received little attention. In the only local study of ecosystem services quantification, Barral and Maceira (2012) evaluated the change in provision of ecosystem services by native grasslands in 1986 and 2006 in Balcarce (*Southern Pampas*). The assessment included changes in soil protection, carbon sequestration, water purification and provision, biodiversity conservation, disturbance control, waste purification and direct goods provision. Results indicate the loss in value of ecosystem services due to land use change from native grasslands to crops.

The number of publications for the Campos was 40% lower than for the Pampas. Subregions with a large proportion of native grasslands were addressed in fewer publications than those with less native grassland. While the *Flooding Pampas* (with 68% of the area under native grasslands) was studied in 49% of the publications, subregions with 70%–89% of the area under native grassland in the Campos (*Campanha, Gondwanic sediment, Corrientes, Graven Merin, Basalt and Eastern Sierras*) were studied in only 17% of publications.

The average strength of evidence is high (2.8/3) (table 4). The lowest values were found for external inputs (use of fertilisers, pesticides and feeding supplements or animal production intensification) and low forage allowance due to a lower proportion of meta-analyses than the other groups.

The drivers with clear impacts on provisioning ecosystem services were land use change, moderate forage allowance, external inputs and flooding (very likely increase), in contrast with low forage allowance (very likely decrease) (table 4).

Assessment of the literature showed a very likely decrease of supporting and regulating ecosystem services due to land use change and low forage allowance (overgrazing). On the other hand, moderate forage allowance, rotational grazing and flooding very likely increased supporting and regulating ecosystem services.

The neutral impact of external inputs on supporting and regulating services was an unexpected result. More in-depth analysis showed that nearly half of the publications dealt with greenhouse gas emissions from livestock systems. The use of external inputs generally resulted in higher aboveground net primary productivity leading to meat production with lower emission intensity. These results counterbalanced the negative effects on water provision and nutrient cycling, exotic plant invasion and bird species presented in ten papers.

6. Discussion

6.1. Impacts of current intensification trends on ecosystem services

Our results show for the first time the spatial consequences of the expansion of soybean for the *Río de la Plata grasslands* (figure 3). We found two types of changes in livestock production, both leading to intensification of livestock production. The first change concerned the increased use of grains as feed in feedlots, which was particularly concentrated in areas with less than 60% native grassland cover; the second change concerned increased stocking rates in subregions dominated by native grasslands (figure 7). The latter may aggravate overgrazing of native grasslands with negative impacts on aboveground net primary and meat productivity, diversity of plant, bird and mammal species, soil organic carbon and erosion.

The intensification of livestock systems by using grains as animal feed in feedlots was shown to decrease greenhouse gas emission intensities (kg CO_2 eq kg^{-1} LW yr^{-1}) due to greater cattle growth rates resulting in increased meat productivity. At the same time, the change from grassland-based to feedlot-based finishing systems was associated with increased environmental contamination by nitrogen and phosphorus, and by pesticides, and with higher fossil fuel consumption levels (Modernel *et al* 2013, Picasso *et al* 2014). As is shown by the coincidence of feedlots and arable cropping (figure 7), the intensification of cattle production through feedlots lead to specialisation of farming systems in which the benefits are lost of animal-crop-grassland interactions that are the mechanisms for erosion control, carbon and nitrogen sequestration, regulation of pests and diseases, reduction in energy demands and biodiversity conservation (Janzen 2011, Peyraud *et al* 2014).

Floristic and animal diversity, climate regulation and primary production were the ecosystem services most frequently studied in the *Río de la Plata grasslands*. The least studied ecosystem services were water provision and nutrient cycling, followed by meat production and erosion control (table 3). A global review of 32 publications on quantification of ecosystem services provision of global grasslands by de Groot *et al* (2012) did not include the *Río de la Plata grasslands*, indicative of the lack of information on this biome. Balvanera *et al* (2012) concluded that ecosystem service research in Uruguay is underdeveloped compared to other countries of Latin America. Research on ecosystem services of native grasslands in Argentina started only in 1990.

We found that the majority of studies on ecosystem services represented (agro-) ecological inventories and did not include analysis of any driver (table 3). If drivers were studied, land use change was addressed most often, followed by grazing and grazing management.

6.2. Alternative future intensification strategies

Few studies addressed alternative land use options. Strassburg *et al* (2014) investigated the carrying capacity of Brazilian cultivated pasture land and found that increasing productivity from the current 32%–34% to 49%–52% of potential productivity would enable meeting the expected growth in food demand for 2040 and spare 18 million ha of Atlantic Rainforest. They, however, did not consider native grasslands and focused their discussion on conventional intensification to increase annual meat production per unit of pasture area. Proposed measures addressed pasture productivity (number of animals per unit of pasture area) and herd productivity (annual meat production per total number of animals). Measures to increase pasture productivity included improved grass mixtures, the inclusion of legumes, reduced tillage, electric fencing, rotational grazing and the introduction of mixed crop-livestock systems. They suggested increases in herd productivity through improved breed selection, reproductive management and earlier slaughtering. Dotta *et al* (2015) showed maximum bird conservation potential in the Northern Campos of southern Brazil and northern Uruguay to be associated with light to moderate grazing on native pastures, defined as cattle ranching on mostly native grasslands with no to medium use of fertilisers and

Table 3. Number of publications that investigated drivers and their impact on ecosystem service provision of *Río de la Plata grasslands*.

	Ecosystem services (number of publications)							
	Supporting, regulating		Regulating			Provisioning		
Drivers	Floristic diversity	Animal diversity	Climate regulation	Water provision and nutrient cycling	Erosion control	Primary production	Meat production	Total
External inputs	3	2	5	6	0	3	2	21
Fire	9	2	0	0	0	0	0	11
Flooding	4	1	0	0	0	1	0	6
Grazing	13	4	3	3	0	8	0	31
Grazing management	13	8	0	0	0	11	1	33
Land use change	14	32	12	4	6	2	0	70
No driver[15]	28	19	14	0	0	8	1	70

[15] These publications described the status of the ecosystem service at specific moments but did not address drivers of change.

exotic grasses and stocking rates of up to 1.0 animal unit ha^{-1}. Alternative land uses included heavy grazing and soybean or timber production. Increasing regional food output or profits by heavy grazing and increasing food and timber production was found to negatively affect grassland bird species. The authors suggest light to moderate grazing as a strategy, while accepting a reduced regional food output as the way to reconcile agricultural production and bird conservation in the region.

Research on native grassland-based systems in the region suggested that ranching based on low to medium grazing intensities may result in significantly higher meat yield than the current average. Changes implemented focused on reversing poor grassland and herd management and the resulting overgrazing. By increasing meat productivity alongside other ecosystem services displacement effects, i.e. meat production taking place elsewhere under environmentally more damaging conditions, would be avoided.

Promising practices that showed positive results in field experiments, and are now considered for dissemination to farmers include:

- Grazing systems based on moderate forage allowances to increase grassland productivity and meat production per animal and per hectare (Nabinger *et al* 2000, Carriquiry *et al* 2012, Soca *et al* 2013a, Cardozo *et al* 2015). On most of the farms this will imply reducing the stocking rates (Carvalho *et al* 2009b, Scarlato *et al* 2015);
- Matching the seasonal livestock feed demand to the biomass dynamics of the native grassland vegetation (Soca and Orcasberro 1992, Maraschin *et al* 1997, Soca *et al* 2013b);
- Adjusting forage allowance and reducing grazing pressure by sheep to avoid sward stratification by tussocks (Da Trindade *et al* 2012);
- Strategic inclusion of ley paddocks on 5 to 10% of the area to meet livestock demand for high-quality forage during reproductive or lactation phases (Royo Pallarés *et al* 2005, Soca *et al* 2013a);
- Strategic feed supplementation to female calves and cows in winter (Straumann *et al* 2008) to improve nutritional status, and therewith reproductive performance (Quintans *et al* 2012).

6.3. The need to engage farmers and policy makers

Implementing such ecological intensification (Doré *et al* 2011) strategies requires important mind-shifts of farmers. In a recent 3 year co-innovation project in Uruguay, Scarlato *et al* (2015) and Ruggia *et al* (2015) found that when farmers managed their production systems based on grass height instead of the number of animals they owned, meat productivity increased by 24% and farm income by 40%. Considering that the increase in soybean prices during the 2000–2010 decade was the major driver of soybean expansion in southern South America (FAO 2007), such higher incomes would provide an important mechanism to avoid conversion to cropping. Whether a 40% increase would be enough to make livestock production competitive should be investigated. In addition to productivity changes, farmers noted decreases in erosion rates associated with maintaining better soil cover.

Further testing of these ecologically intensive grassland management practices with farmers is urgent. In addition, the ecosystem services provided by native grasslands need to be recognised to open up opportunities for financial incentives, for instance through value chains that enable beef producers to participate in 'high quality' market segments (Tessema *et al* 2013). An on-going initiative in the region is the certification of meat produced on native grasslands. Currently, 200 000 ha of native grasslands are certified

Table 4. Trends in the impact of drivers on ecosystem service provision by *Río de la Plata grasslands*.

	Provisioning services					Supporting and regulating services				
Driver	Publications (N°)	Decrease (%)	Increase (%)	Strength[17]	Conclusion[18]	Publications (N°)	Decrease (%)	Increase (%)	Strength[17]	Conclusion[18]
Land use change	3	0	100	3	Very likely increase	84	87	13	2.9	Very likely decrease
Moderate forage allowance[16]	19	0	100	2.9	Very likely increase	8	0	100	2.9	Very likely increase
Rotational grazing[16]	0	0	0	0	—	4	0	100	3	Very likely increase
Low forage allowance[16]	4	100	0	2.5	Very likely decrease	11	100	0	3	Very likely decrease
Other[16]	0	—	—	—	—	11	9	91	2.9	Very likely increase
Grazing	8	40	60	2.9	Neutral/undecided	35	39	61	2.9	Likely increase
External inputs	8	0	100	2.5	Very likely increase	18	59	41	2.8	Neutral/undecided
Flooding	1	0	100	3	Very likely increase	6	20	80	3	Very likely increase
Fire	0	—	—	—	—	15	50	50	3	Neutral/undecided

[16] Drivers together comprising 'Grazing management'.

[17] Strength of evidence is an average of a three-point scale: High strength evidence (value = 3; studies from controlled field experiments, observations with sound methodologies or meta-analyses); intermediate strength evidence (value = 2; narrative reviews), and low strength (value = 1; publications based on opinion).

[18] Conclusion is drawn by considering the percentage of publications with positive (increase) or negative (decrease) effects on the ecosystem service provision. Very likely: 80%–100%; likely: 60%–80%; neutral/undecided: 40%–60%.

and export of certified meat has started (Alianza del Pastizal 2015).

For biomes in South America such as Amazonia and Cerrados public policies for nature conservation have been put in place (UNEP, CIUP, ACTO and CIUP 2009, Ministério Do Meio Ambiente 2015). Policy-based conservation of the *Río de la Plata grasslands*, however, is largely absent, causing Overbeck *et al* (2007) to call it a 'neglected biome'. In *Río de la Plata grasslands* region institutional protection of native grasslands through a national park status is limited to 0.5%, 0.3% and 0.2% of the area of Rio Grande do Sul, the Pampas and Uruguay (Bilenca and Miñarro 2004). Dotta *et al* (2015) reported higher values for formally protected parks in the Campos (2%). The Brazilian Legal Reserve law of 2012 stipulates that 20% of every property must be maintained under natural vegetation (Presidência da República 2012). The Convention on Biodiversity provides an international legal basis for *Río de la Plata grasslands* protection by calling for 17% of all terrestrial biomes to be formally protected by 2020 (Aichi Target 11). Current policy measures in particularly Argentina and Uruguay thus remain far from what has been internationally agreed.

7. Conclusions

Land use change is driving intensification of livestock systems in the *Río de la Plata grasslands* region, thereby decreasing the area of native grassland and the ecosystem services they provide. Without intervention, these developments are likely to lead to the disappearance of native grassland-based livestock production systems and the associated ecosystem services provided, either by the replacement of native grasslands by crops or leys, or by their degradation through overgrazing.

We identified the need for more knowledge of ecosystem services provided by native grasslands and on livestock production strategies that support these services. The evidence presented in this paper suggests that it is possible to combine high levels of ecosystem service provisioning and meat production. Working with farmers on changing their management strategies and designing policies to enable economic conditions for this to happen, appear promising avenues to combine production and conservation in this neglected biome.

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